NanoByg - a survey of nanoinnovation in Danish construction. Executive summary in English

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A survey of nanoinnovation in Danish construction

Executive summary, English

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EXECUTIVE SUMMARY - WHY NANOBYG?

Lundgaard & Tranberg. Industrikollegiet, 2004, København. Photographer: Michael Beck, Lundgaard & Tranberg.

Lundgaard & Tranberg Industrikollegiet, 2004, København. Photographer: Michael Beck, Lundgaard & Tranberg.

Nanotechnology is about the manipulation of matter at the nanoscale. Few technologies have created so much hype and attracted so much funding globally as nanotechnology has the last 5-10 years. There is a global race to take the lead in what many expect to be the next industrial revolution. The visions and hype are considerable, however the technology is still at an early stage of development and commercialization has just begun.

The construction sector was among the first to be identified as a promising application area for nanotechnology back in the beginning of the 1990s. But today we see that the construction industry is falling behind other sectors in applying nanotechnology.

This report looks into the perspective and potentials of nanotechnology in construction and noticeable discusses the possibility for a Danish initiative – called NanoByg - in this area.

The core challenge that a possible NanoByg initiative should address may be formulated like this:

How do we create innovation in the intersection between the needs of the construction sector and the emerging nanotechnological opportunities?

Behind the idea of NanoByg lie three assumptions:

1. The enabling character of nanotechnology means that it has the potential to create radical and systemic innovation within architecture and construction.

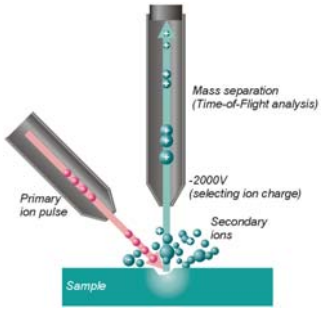
2. Current (Danish) nanoscience is to a large extent oriented at applications in other industries than construction – so it is currently unlikely to have a significant impact on the construction industry.

3. The fragmented nature of the construction sector means that it is likely to have a low uptake and spread of such a new and advanced technology as nanotechnology unless careful action is taken.

The report consists of a short analysis of the innovation trends and dynamics of respectively construction and nanotechnology, and a mapping of the activities and actors that are or could become relevant for the application of nanotechnology in architecture and construction. The focus here is very much on identifying potential nano-activities of relevance for construction and not just existing activities, which, as our mapping shows, are quite limited.

NANOTECHNOLOGY IN CONSTRUCTION:

TRENDS, OPPORTUNITIES AND CHALLENGES

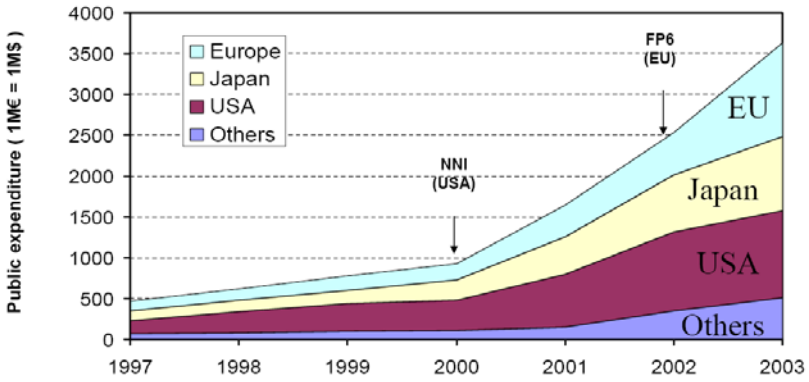


TOF-SIMS (Time-of-flight secondary-ion-mass-spectroscopy) Instrument for mapping the chemical composition of a material within a few nano-meters (Niels B. Larsen, Risø)

Nanotechnology has attracted a huge amount of interest around the globe over the last 5–15 years. The clearest indicator that something special is going on in nanotechnology is investment: it is estimated that in 2004 around USD 9,000m were invested globally in nanotechnology R&D – a trend that seems to be on the increase.

There is a global race to take the lead in what many expect to be the next industrial revolution, with the US currently in front, but with Asia also very much on the move and the EU lagging somewhat after. Nanoscale efforts nearly doubled from 1997 to 2000 in both the EU and Japan, and in the US between 2000 and 2004. Emerging strong nanotech countries are China, India and Russia.

Public expenditure in nanotechnology is growing by ~40% annually to around 3.5 billion €/$ in 2003.



Source: European Commission (2003)

Nanotechnology is an enabling technology in the sense that future nanotech breakthrough inventions are expected to have pervasive impact on existing industries and even lead to entirely new industries. Such a possible major industrial transition is likely to take 20–30 years if nanotechnology follows similar gestation times to those of other general-purpose technologies like biotechnology and ICT.

KHR, Jens Bangs Gæstebolig. Photographer: Ib Sørensen

Henning Larsens Tegnestue. Woodland boliger, Sverige. Visualisering: HLT

Nanoscience is not new, but it is not until recently that we have begun to see an application of nanoscience and technology in commercialized products. The level of commercialisation varies considerably, but in many areas development is still experimental. In the countries most advanced in nanotechnology (US, Japan, Korea, Taiwan), there is considerable industrial involvement and private investment makes up at least 50% of the total. In the US, private investment is at the same level as public investment, and in Japan, private investment makes up as much as 75% of the total.

In the EU, and this applies also to Denmark, the level of nanoscience is high, but we are somewhat behind the leading countries in industrial uptake of nanotechnology (whether measured in patents, start-up companies and private investments). This is, however, not specific to nanotech, but general for EU innovation patterns.

Organic solarcells, Frederik Krebs, Risø. Photographer: Gitte Sofie Hansen.

THE DEVELOPMENT OF NANOTECHNOLOGY IN DENMARK

As stated earlier, Denmark has a strong nanoscience base, but relatively modest amounts of industrial nano-activity. This is partly due to the limited role of big industrial players in the Danish economy. Since 2003, public money has been earmarked to nano-research, and this had a major and immediate effect on the Danish innovation system. Several new nano-research centres and networks are springing up or are being reinforced. Today, Danish nanoscience takes place mostly in four big nano-centres: iNANO[1], Nano SDU[2], Nano•DTU[3] and the Nano-Science Centre[4].

A mapping exercise carried out in 2005 identified 58 predominately Danish companies who were collaborating in some way with Danish nanoscientists. Most of them were small start-ups, but there were also a few of the more established large innovative Danish companies among them. One big company stands out, playing a central role in Danish nanoscience and technology development: Haldor Topsøe A/S, a world-leading producer of environmental catalysts and steam reformers. In the catalysis area, Denmark is in the scientific and technological forefront. Apart from this well-established area (which also feeds into ceramics and hydrogen research), the other main emerging nano-application area in Denmark is the medical area.

> *Case: SCF Technologies*
> *The importance of the focusing process that takes place when a technology meets the market is well illustrated in SCF Technologies. They have developed a "technology [that] makes it possible to use such natural elements as water and carbon dioxide under high pressure and temperature in near/supercritical conditions to create sustainable solutions for such problems for society as obesity, waste disposal and lack of oil" (www.scf-technologies.com) .*
>
> *This is nanotechnology in the true sense of enabling and general purpose technology that treat materials in general, which they then apply to different industrial processes. They can lower the fat in potato chips or produce oil, what they will focus on and develop the most is of course highly dependent upon their encounter with the market. Today they work mainly in three different areas, that is with three different applications: Energy, Food and Advanced materials. However, they only do this as long as there is a development potential within those sectors…*

NANOTECHNOLOGY IN CONSTRUCTION

Today we know little of the actual and potential application of nanotechnology in construction. Only four reports are available, all fairly recent reports or papers which more discuss expectations and highlight some cases than bring thorough analysis of trends and impacts.

"If construction continues to ignore nanotechnology it will be the one left paying a fortune for a last minute ticket it could have had for a song if it had acted earlier"

Nanoforum Report, 2006

The main conclusion from the mentioned analyses is that there is a considerable but underexploited potential for nanotechnology in construction. Since materials are construction's core business the sector is expected to be an important beneficiary of new nanomaterials. In the Nanoforum report a survey among international nanoconstruction experts predicted that many nanoadvances would arrive in construction within five years. The sheer size and scope of the

[1] University of Aarhus and Ålborg University
[2] The University of Southern Denmark
[3] Technical University of Denmark and Risø National Laboratory
[4] The University of Copenhagen and the Royal Veterinary and Agricultural University

construction industry means that the accompanying economic impact will be huge.

The construction industry has often been accused to be a low-tech industry weak in innovation. An overall conclusion to the development of the industry is thus that productivity and the rate of innovation has been considerably lower in the construction industry compared to the economy as a whole during the last 20 years. (National agency for Enterprise and Construction (NAEC), byggeriet fra tradition til innovation). Accordingly, the percentage of R&D of turnover is considerable lower for the building and construction industry compared to the Danish industry as a whole, as shown in the figure below. Furthermore the investment in R&D has been declining in recent years.

In 2004 the total production value of the construction industry was 448,7 billion ddk. In total the sector employed 306.000 persons.

Statistics Denmark
www.statbank.dk

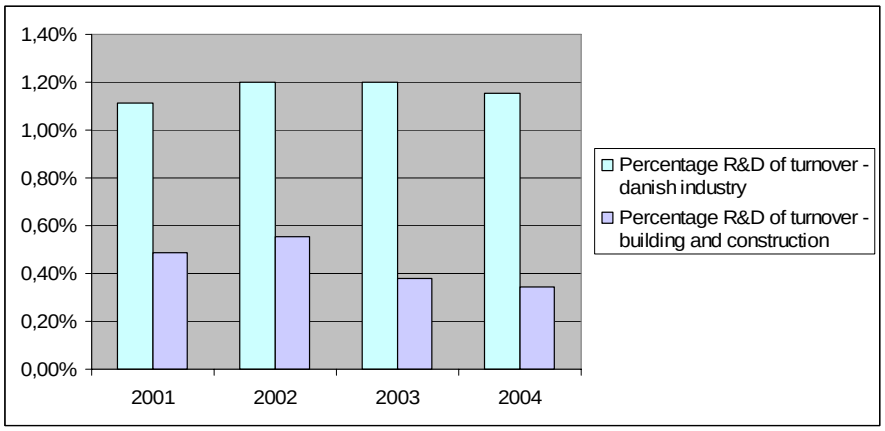


Figure 1:Percentage R&D of turnover
Source:
R&D figures are from Dansk Forskningsstatistik.
Turnover figures are from Danmark Statistik.

As elaborated below, innovation in construction is conditioned by some very fragmented and complex organisational structures, which distribute opportunities, risks, willingness and resistance uneven across different actors throughout the value chain. To support innovation it is thus necessary to be both strategic and creative in order to establish coherent and dedicated networks or alliances of actors and resources.

Some of the most commonly identified challenges to innovation in construction are:

1. A long value chain
2. Project based production
3. Organizational fragmentation
4. Different incentives and interest along the value chain
5. Rigid regulatory standards
6. Lack of international competition

The long value chain combined with a project based production creates a fragmented and hard to grasp structure in the construction industry. This fragmented character of the construction industry together with its project based organization makes it hard to induce systematic learning and knowledge sharing. A prerequisite for persistent learning and innovation is to enact a system that can integrate and spread knowledge between actors in the different phases of the value chain.

Dorte Mandrup Arkitekter. Kvarterhus Jemtelandsgade, eksteriør. Photographer: Jens Markus Lindhe

Dorte Mandrup Arkitekter. Kvarterhus Jemtelandsgade, interiør. Photographer: Jens Markus Lindhe

Architects, engineering consultants, entrepreneurs, and clients/commissioners have their saying on each new construction project and who ought to participate. Different incentives and interests along the value chain hinders such cooperation. An example is that the contractors incentive to engage in development projects with material manufacturers are often limited, as the ownership of the innovation goes to the material manufacturer.

Regulatory standards generally play an important part in construction, often inhibiting innovation. At the European level much work is being done in order to establish common regulatory standards furthering the international competition on building materials. Generally speaking the traditional strong home market orientation of the Danish construction industry is beginning to be challenged by the rising globalisation of the economy. There is an early burgeoning, but silent, industrialization on the way. Modular construction systems are rising, e.g. in wooden houses or new materials such as glasfiber, prefabricated bathrooms or kitchens are being installed ect., often manufactured in cheap Eastern European countries.

MAPPING THE NANO-CONSTRUCTION ACTIVITIES

The major goal of this report was to identify the potentials of nanotechnology to solve the needs and problems of the construction sector. In this work six nano-pillars emerged that structure the potentials of nanotechnology in relation to the construction industry. The overview illustrates the great variety and scope of nanotechnology, the many emerging technological areas, and the broad application opportunities which address almost all aspects of construction.

The six nano-pillars are:

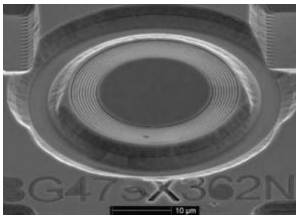
1. Nanostructured materials,
2. Nanostructured surfaces,
3. Nano-optics,
4. Nanosensors & electronics,
5. Nano-related integrated energy production & storage
6. Nano-related integrated environmental remediation

These pillars form the basis of our mapping of Danish nano-activities. We have tried to start linking these up with specific construction requirements, needs but this task needs more work. It entails developing new problem definitions in a long-term dialogue between nano-actors and construction actors.

Table 1 below gives an overview of Danish nano-research and technology areas and their construction relevance identified during the NanoByg pre-project.

The overall conclusion from the mapping exercise is that the expected gap between nanotechnology and construction has been confirmed. Danish nano-actors are not very active in the construction sector and know little about its needs, and the construction sector is even less active in nanotechnology and knows very little about its possible implications for the sector.

Further work is needed to clarify in more depth how nanotechnologies may remedy specific problems and requirements of the construction sector, e.g. indoor climate, fire and risk protection, energy efficiency, lighting systems, efficient production methods, waste handling, etc.



Researchers at the National Institute of Standards and Technology (NIST) have made semiconductor light-emitting diodes (LEDs) more than seven times brighter by etching nanoscale grooves in a surrounding cavity to guide scattered light in one direction.

July 17 issue of Applied Physics Letters.
Credit: NIST

The overview shows that nanotechnology potentially may offer many novel solutions in Danish construction, and improve many properties both in relation to improving production processes, materials and components for newbuilds, and renovation of existing buildings, as well as influencing the uses, living conditions, and disposal of buildings and civil works. Not least, energy and environmental opportunities seem to be considerable.

However, many of the novel solutions are in an early stage of development, although others are fully commercial. In most cases, further development is needed to help the many identified science and technology areas address the specific problems and conditions of the construction sector.

Nano-related research and technology areas	Relevance for the construction sector (main topics)	
Topics in Table bb	**Application in**	**Important Properties or Functions:**
1. Nanostructured materials 1) Composites 2) Wood 3) Nanoporous materials 4) Polymers 5) Other materials	Insulation materials, Load carrying materials, Interior construction materials, Exterior construction materials, Surfaces	Strength, Lightness, Durability Production and execution Indoor climate Maintenance Energy efficiency Resource efficiency Recyclability Degradability Fire protection
2. Functional Surfaces 1) Chemically modified surfaces 2) Physically modified surfaces	Building surfaces, Water systems, Coating of load carrying materials Ventilation, Heating Electrical, Lighting, Sensors, Integrated functions	Durability, Cleaning, Hygiene, Maintenance, Strength
3. Optics 1) Planar lightwave circuits 2) Photonic crystal fibers 3) Light emitting diodes, LED 4) Integrated optical sensors	Sensors, Integrated functions, Electrical and lighting systems, Fibre cables	Energy efficiency, Climate control, Fire and other safety, Cleaning
4. Sensors & Electronics 1) Monitoring 2) Transmission	Biosensors, Optical sensors, Chemical sensors, Micromechan Gas sensors, Microorganism sen Electroactive materials, Water systems	Monitoring and control, Integrated functions in electrical and lighting systems
5. Integrated energy production and distribution/storage 1) Fuel cells 2) Solar cells 3) Other	Solar cells, Hydrogen storage, Fu cells, Exterior materials, Ventilati Heating	Energy efficiency and self-sufficiency, Resource efficiency, Indoor climate
6. Integrated environmental control and 1) Catalytic cleaning 2) Other separation/cleaning processes 3) Risk assessment	Water systems (supply and waste Catalysis, Separation processes, Waste systems	Cleaning and hygiene, Indoor climate, Integrated functions, Degradability, Resource efficiency, Energy efficiency Substitution of Hazardous materials, Production and execution,
General nano-research and competenci 1) Synthesis 2) Manufacturing 3) Characterisation	Fundamental material understand and design	

Table 1 Overview
Nano-related areas and their relevance for the construction sector

THE SCOPE FOR NANO-CONSTRUCTION

KHR, Fiberline.

KHR, Fiberline.
Photographer: Torben Eskerod.

Several analyses have pointed to the low research and innovation level in construction. Moreover, the Danish research and development effort in construction has been strongly declining in recent years, both in comparison with other sectors and in relation to other OECD countries. This leaves the industry in a weak position to meet future challenges, such as increasing competition and new markets due to globalisation, new strict energy efficiency and environmental demands, indoor climate requirements, the rise of modular design and urbanisation. The latest Danish vision plan for construction, Vision 2020, emphasises how the construction sector needs to be better at opening up to the surrounding world and absorbing new science-based knowledge to address these challenges. The question is whether nanotechnology, as a highly science-based enabling technology, could offer interesting novel solutions to these challenges.

The literature is very sparse, which reflects the early stage of commercial development. But expectations are high, e.g. that new nano-based light, strong, thin, durable, and self-repairing materials may lead to better buildings and civil engineering. Not least, there are expectations of much higher energy and ecological efficiency. Our mapping of emerging nanotechnological areas and the discussion of their relevance for construction shows a wide range of potentially novel nano-solutions in construction.

Nanotechnology open up new opportunities with a interdisciplinary and visionary character, that cut through the traditional practices of the construction sector. This can facilitate creative processes in the construction sector and the search for novel solutions, i.e. lead to new kinds of need-driven innovation, inspire completely new research and development agendas, and create platforms where new constellations of actors in the construction value chain could meet and address radical and systemic innovations.

This report carries five main arguments why it is important to stimulate nanoconstruction in Denmark:

First, there is a need for better communication between the construction industry and the nanocommunity, because a low degree of knowledge sharing between them.

Second, nanotechnological development is entering a decisive realisation phase in which the dominant application areas are consolidating and nanotechnology is becoming more specific; An early and large-scale initiative from nanoscience and nanotechnology in the construction area could help seed nanotechnological development in Denmark in the direction of construction.

Third, we have found considerable policy interest for the NanoByg initiative among the Danish ministries, not only in relation to construction and transport policy, but also science and innovation policy, environmental and energy policy and health and labour conditions. At the EU level, nano-policy is starting to focus on wider industrial applications and nano-construction is among the areas indicated.

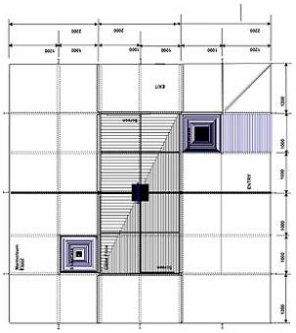
Fourth, nano-construction activities are already emerging around the world. Much of it is hidden among other nano-activities and is not easily identified. If a Danish initiative is established, we have a good opportunity to team up with these

A 2.5 kg brick is supported on top of a piece of aerogel weighing only 2.38 grams (NASA)

and join the technological leading edge in the development of the nano-construction field.

Fifth, we have identified only limited current activities in the field of nano-construction among Danish nanoscientists, nano-companies and construction companies. Many nanoscientists and nano-dedicated companies lack insight into the requirements of the construction industry, and a large part of the construction sector lacks insight into the nanotechnological opportunities now available. As a result of the activities and dialogues of the pre-project we have identified many interested actors, as shown by our contact list and stakeholder map. However, the potential of nanotechnology still needs considerably more demonstration and discussion among the many different actors in construction.

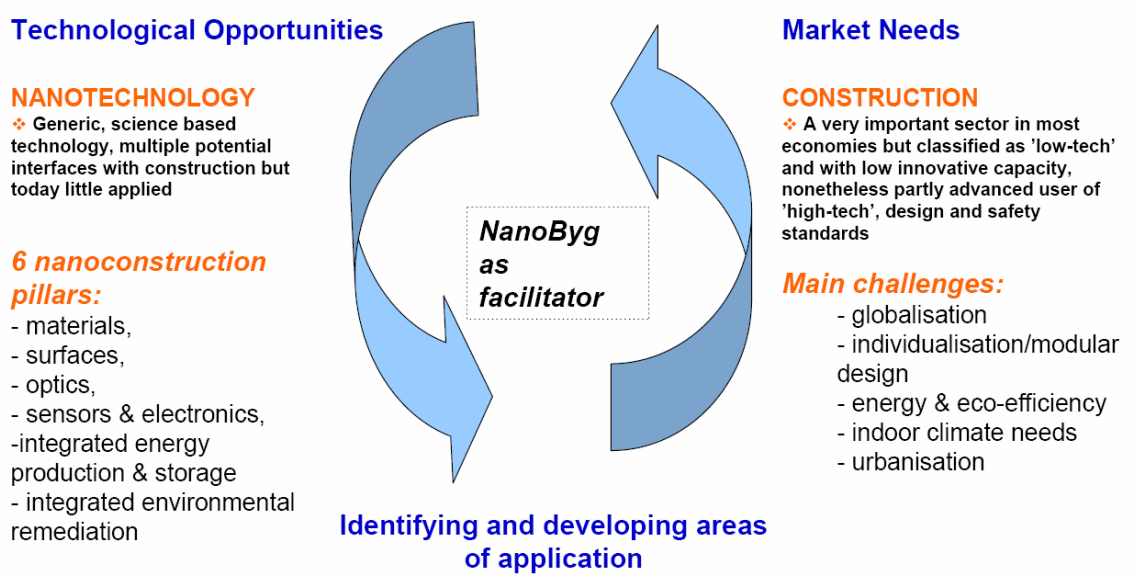
A WAY AHEAD: NANOBYG INITIATIVE



The Glass House, Sidney, Australia, 2003. Dr Carl Masens, Institute for Nanoscale Technology, University of Technology Sydney 2003 (UTS). Architect James Muir. In collaboration with CSIRO, Haico Schepers, Arups in London, Pilkington Active Glas.

In general we have identified barriers and possibilities for innovation co-operations between the construction industry and nanocommunity. Some co-operations already exist and there are also innovations in the construction industry that build on a cooperation with the nanocommunity. The aim of a future NanoByg is to overcome the barriers for cooperation through analysis and practical work. In this NanoByg go beyond traditional research projects; in that it has both an innovation project and an innovation research perspective on the relation between construction industry and the nanocommunity. It is to focus on project and institutional levels of innovation to facilitate a meeting ground where the market needs of the construction sector can show areas of application to the technological opportunities nanotechnology.

In this context the construction industry is material and component producers, architects, consultants, entrepreneurs, clients and owners. The nanocommunity is seen as universities, sector research institutes and nanotechnology intensive companies. The primary goal is to get a dialogue going, a dialogue that is not only focused on finishing a limited set of projects, but to invoke a continuous dialogue and establish channels for knowledge sharing among the construction industry and the nanocommunity. There is a demand for a system that can enact new forms of co-operations and system integrators in a sector characterized by conservative modes of business. This makes a potential NanoByg initiative in a great challenge, but also a task with great potential.



NanoByg would look into that whole value chain of the construction industry from idea phase and design to the concrete building project. The focus is on the relation between research and innovation and especially how we can secure the role of the construction industry as driver in nanotechnolgical innovation projects. The aim is to make active the visions and problem of the construction industry in the nanocommunity.